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pheric transparency during the two or three hours necessary to the determination. It is this defect of the uniformity of the atmospheric transparency which requires us to make the measurements at so many stations in order to get a satisfactory result.

Both the Mount Wilson and Calama observations indicate that the solar radiation was above its normal in the year 1918, having an average value of about 1.95 calories per square centimeter per minute. The mean value for many years was 1.93.

ROTATING PROJECTILES FROM SMOOTH-BORE GUNS

BY C. G. ABBOT

SMITHSONIAN INSTITUTION, WASHINGTON

Read before the Academy, April 29, 1919

In the late war much use was made of trench mortars. This kind of ordnance consists essentially of a smooth tube with a firing pin at the bottom. The projectile carries a shotgun shell at the rear. It is dropped down the smooth-bore barrel by the soldier and the firing pin explodes the primer on the shotgun shell. This in its turn explodes the charge of propellant which throws the shell into the enemy's lines. Many of the trench mortar shells tumbled end over end as they went over, but some were provided with fins which retained them in approximately steady flight. However the trajectory of these shells was by no means ideal.

It occurred to me to try to secure sufficient rotation to produce steady flight by means of the turbine principle applied to the shells. Unfortunately the research was proposed to me only a few days before the armistice was declared so that by the time preliminary tests were made it was too late for the device to be of war service. However, the results appeared to be so promising that I have made numerous further experiments with a smooth-bore musket of 0.9 inch diameter which had seen service in the Civil War.

The elongated ojival projectile was made in two parts in my experiments, the one a tough steel rear part chambered out to contain the propellant, the other an aluminum nose provided with a steel plug at the rear for screwing into the steel part of the projectile. The steel plug serves the double purpose of closing the chamber and attaching it to the front part. With the aluminium part in front such projectiles are particularly well calculated for tumbling, and invariably did so when fired in the usual manner. At the extreme rear of the steel part of the

projectile a plurality of bell-shaped bores were provided, leading tangentially from the chamber within the projectile to the rear where they emerged into the barrel of the gun. On screwing the aluminum nose with its steel boss into the opening of the chamber the whole presented the appearance of an ordinary elongated projectile except for the bell-mouthed bores visible at the rear. When the gun is fired the propellant within the chamber is ignited by priming contained in the tangential apertures.

The outflow of the gases through the bell-mouthed bores, while they would give some rotation, owing to their friction within the chamber, would fail to give sufficient rotation if it were not that steel pins are inserted across the chamber to form a sort of baffle, so that the outflowing gases may react against this baffle and so tend more strongly to rotate the projectile.

It was feared that the combustion would not be completed, or at least that the gases would still remain in the chamber at high condensation at the time when the projectile left the muzzle of the gun. If this were the case it might easily be that owing to some slightly unsymmetrical construction of the bell-mouthed bores some tendency to deflect the flight of the projectile would be caused thereby by the delayed outrush of the residue of gases. In order to avoid this, the end of the barrel was continued by a tube extending some 10 inches beyond the former muzzle and at the rear of the tube where it joined the barrel there were drilled a number of holes so that the gases might escape therefrom, and relieve the pressure within the chamber of the projectile while still it was subject to guidance from the lengthened barrel of the gun.

Very satisfactory results have been obtained in firing these special projectiles. This method of securing rotation of projectiles appears to be suitable not only for trench warfare but for all varieties of ordnance larger than 1 inch in diameter. Rotations as great as one rotation in 18 calibers have been obtained thereby. It is customary to employ about one rotation in 30 calibers in the ordnance of Europe. The United States employs one rotation in 25 calibers for a large number of its heavy guns. My experiments seem to show that one rotation in 40 or 50 calibers is sufficient to prevent any appreciable deflection of the shells in flight.

The experiments have been conducted within the enclosure of the Astrophysical Observatory, so that it was impracticable to employ heavy charges so as to get very high speeds of flight, but within the range of the experiments I have found by shooting through a succession of paper screens and observing the holes with a theodolite that within the length

of the observatory enclosure there is no measurable lateral deflection of the projectile while in flight. Truly round holes are always left by the rotating projectiles. Very striking results were obtained in an experiment made in Virginia in the presence of a number of Ordnance Officers. Two successive shots were fired at a target in one of which the projectile was made to rotate by means of the included charge and in the other of which the projectile was fired by powder outside of itself. In the one an excellent hit was made, leaving a true round hole, while in the other it happened that in the tumbling of the shell in the air it reached the target exactly broadside. The officers were naturally much impressed by this striking exhibit.

As in most of the investigations we undertake, the same general idea had long before occurred to others. Patents for somewhat similar devices were granted as long ago as the Civil War. So far as I am aware, however, no one hitherto has attained so good a measure of success in applying the turbine principle to projectiles.

MEANS OF MEASURING THE SPEED OF PROJECTILES IN FLIGHT

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In the course of the experiments on rotating projectiles from smooth bore guns I desired to measure the speed of flight in some instances, and as I lacked the usual chronographic apparatus employed by artillerists the following substitute occurred to me and proved very satisfactory after a few trials.

The projectile was fired obliquely across a horizontal beam of light reflected into the observatory from the siderostat. The solar beam was entirely cut off by a diaphragm at the wall of the observatory, except as it passed through two round holes about 6 inches apart. The shot was fired through the left hand one of these holes. About 2 meters inside of the observatory another smaller diaphragm with a small aperture in it was placed opposite to the second or right hand hole. The direction of the gun was so arranged that the shot passed through the hole in this second diaphragm also. About a meter beyond the second diaphragm was placed a double tinfoil screen, the two tinfoils being separated by a sheet of cardboard and connected by wires respectively to a circuit con-